

Pressure-Tolerant Batteries for Autonomous Undersea Applications

J. Scott Willcox
Bluefin Robotics Corp.
301 Massachusetts Avenue
Cambridge, MA 02139
Phone: (617) 498-0004 Fax: (617) 498-0067 email: swillcox@bluefinrobotics.com

Frank van Mierlo
Bluefin Robotics Corp.
301 Massachusetts Avenue
Cambridge, MA 02139
Phone: (617) 498-0010 Fax: (617) 498-0067 email: mierlo@bluefinrobotics.com

Contract Number: N0001401C0205
<http://www.bluefinrobotics.com>

LONG-TERM GOALS

This work will result in significant improvements in underwater battery packs. Such systems will power AUVs in scientific and military applications, as well as the critical offshore oil and sub-sea telecommunications industries. Our market study shows that, by 2005, AUV applications alone will constitute a multi-million dollar market for these batteries. In addition, the prospects for non-AUV uses are at least as promising.

OBJECTIVES

It has long been known that batteries can be *pressure compensated*, i.e., modified to operate at depth. Unfortunately, these modifications bring along severe restrictions on vehicle handling as well as increased maintenance requirements, neither of which is acceptable for the new generation of small, low-cost, Autonomous Underwater Vehicles (AUVs). Recent advances in electrolyte and lithium ion cells open the possibility of *pressure-tolerant batteries*, i.e., batteries that are intrinsically capable of withstanding the pressure with negligible modification. In this proposal we will demonstrate how such pressure-tolerant batteries can increase an AUV's energy capacity by 50% or more, with no reduction in vehicle payload and no increase in vehicle size. To get a corresponding increase in capacity through better electrochemistry or cell manufacturing would require many millions of dollars and many years of R&D effort, with no guarantee of success. In our Phase I effort we demonstrated the feasibility of pressure-tolerant batteries.

The objective of phase II is to gain the detailed understanding of COTS cells that is required to maximize their utility for undersea applications. Success requires testing the electrical and mechanical properties of battery packs at several scales – single cell, small collections of cells (up to 14 cells), a 1.1 kWh, and a full-scale 5.5 kWh. Characterization will have to include realistic electrical loads as the cells would experience in an AUV, and the application of high pressure over the discharge cycle. In the process of characterizing the cells we will identify potential manufacturing difficulties and resolve them.

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 30 SEP 2001		2. REPORT TYPE		3. DATES COVERED 00-00-2001 to 00-00-2001	
4. TITLE AND SUBTITLE Pressure-Tolerant Batteries for Autonomous Undersea Applications				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Bluefin Robotics Corp.,,301 Massachusetts Avenue,,Cambridge,,MA, 02139				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT This work will result in significant improvements in underwater battery packs. Such systems will power AUVs in scientific and military applications, as well as the critical offshore oil and sub-sea telecommunications industries. Our market study shows that, by 2005, AUV applications alone will constitute a multi-million dollar market for these batteries. In addition, the prospects for non-AUV uses are at least as promising.					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 5	19a. NAME OF RESPONSIBLE PERSON
a REPORT unclassified	b ABSTRACT unclassified	c THIS PAGE unclassified			

The *Objectives* of the *Base Proposal* are to:

- Build a 1.1 kWh prototype battery pack and operate it in an AUV.
- Understand the parameters affecting the electrical performance of cells subjected to the relevant conditions expected in a full-scale pressure-tolerant battery pack operating in an AUV.
- Understand the requirements for the mechanical packaging of cells for pressure-tolerant battery packs, including thermal management needs, electrical interconnect limitations, and design for manufacturability concerns.
- Understand the nature of the fundamental failure modes of the cells, particularly those relating to operating cells in large battery packs, and creating specifications and guidelines to minimize the possibility of cell failures and mitigating the consequences of cell failures.
- Have in hand a baseline design for a 5.5 kWh pressure tolerant battery pack.

To design a pressure-tolerant battery pack we must answer these questions:

- What is the best electrical architecture?
- What is the best charging method?
- How do we minimize (or mitigate) the failure modes of the cells?
- What are the monitoring requirements for voltages, currents, and temperature?
- What are the thermal management requirements?
- How will the cells be packaged, and what constraints are imposed by the choice of cells?
- How do we minimize manufacturing costs while maximizing reliability?
- What storage, use, and handling protocols are required to maximize service lifetime?

WORK COMPLETED

We have built nine prototype 1 KWh packs and we have tested these packs extensively in real life field conditions. Some of these packs have failed under different conditions and some are still working. The failures have been very valuable in understanding this technology and the engineering challenge that we need to overcome. Packs have been tested in pressure chambers with pressures up to 8000 psi and four packs have been used on actual dives to 12500 feet. We are making good progress with this technology. Packaging remains a problem and is now our area of focus to increase the reliability.

We completed a comprehensive study of electrical connection methods. We have invested in a welder to make the connections to the batteries. A focused optimization program was completed to make this machine produce reliable connections.

A first prototype of a battery monitoring board was designed and built. Automated charging and discharging equipment has been designed. Life-cycle testing of a full 1 KWh pack has started. Our testing has shown that with the right design thermal management of the battery can be controlled. We have identified several failure modes. As expected over charging and over discharging leads to failure. It is encouraging that even under abuse conditions we have not had any catastrophic failures that would threaten human safety in the field.

Future Work: In the coming months we will,

- Improve the mechanical design to increase reliability,
- Design a large (>3 KWh) pack,
- Build a second generation monitoring electronics board with increased reliability,
- Continue life-cycle testing, and
- Continue field testing.

IMPACT/APPLICATIONS

This work will create a better, safer, cheaper and more reliable underwater battery that can be used in all autonomous underwater applications.

TRANSITIONS

Large suppliers that cater to the laptop computer and mobile phone market dominate the battery market. The product volume and margins in these global applications allow these suppliers to keep the technical edge in battery technology. For these companies the market for special marine batteries is too small to be of interest. For deep-water applications, what is needed is a value-added reseller who takes the existing standard batteries and uses them as components for a marine battery pack. This is in a nutshell what we propose to do. Bluefin sees these cells as a new product line focused on underwater applications, where they will be for sale to all government, industry and academic users

It is Bluefin's express mission to commercialize high-tech underwater equipment. Apart from using the resulting battery technology in our own Autonomous Underwater Vehicles, we will also make the resulting battery pack available to the underwater community. At the moment Bluefin has orders for twelve AUVs. All of these vehicles would benefit from the battery technology that will result from this program. As Bluefin continues to sell more AUVs, the market for the Bluefin's pressure-tolerant battery packs will grow accordingly.

There are numerous applications for a well-designed marine battery pack. The offshore market requires a large suite of instrumentation in their sub-sea completions. A pressure tolerant battery pack combined with an acoustic modem is a very attractive alternative to laying several miles of power and signal cables. While we start with the fast-growing AUV market as already mentioned, other applications include the deployment of Ocean Bottom Seismometers and Acoustic Transponders. By adding up the potential for each application we arrive at a market estimate for this technology of \$5,000,000 per year. This is the same order of magnitude as today's market for Silver Zinc batteries. As AUVs become more accepted in both the commercial and military domain, the market for pressure tolerant batteries will grow rapidly

Faithful to our commercial mission Bluefin did sell prototype pressure compensated packs to James Cameron (the producer of the movie *Titanic*). Together with his two brothers, Mike and John, James Cameron is currently producing a 3D documentary movie of the *Titanic*. Three weeks before setting sail to capture new footage of the *Titanic*, the Lithium ion batteries of the specially designed camera ROVs had failed and James Cameron called Bluefin for help. Thanks to the previous efforts that were funded under this SBIR, it was possible for Bluefin to design and built prototype batteries in seven days. This saved the expedition and On September 27th, 2001 the Cameron brothers returned to Halifax

with some spectacular footage from inside the *Titanic*. The new documentary titled “*The Ghosts of the Abyss*” will soon air as a 3D large screen format. This was the first sale of this new technology.

More mundane and probably more important, we will implement the results of this work on the Bluefin AUVs that are purchased by ONR and CSS. This fall we will deliver an AUV to MIT for scientific missions. This vehicle will be delivered with pressure compensated batteries. Early 2002 we also expect to use this new technology on the two commercial AUVs that Bluefin is currently building for Thales.

RELATED PROJECTS

The *Battlespace Preparation AUV* (BPAUV), shown in Figure 2, is an ONR-funded program to produce a modular AUV for autonomous bottom mapping and classification. The high-resolution, multi-beam Klein 5000 side-scan sonar carried by the BPAUV allows the vehicle to be used to locate mine targets. Due to its modular section design, the BPAUV is capable of carrying different or additional sensors and payloads.



Figure 2: The Battlespace Preparation AUV (BPAUV) provides autonomous bottom mapping/classification and target localization capabilities for MCM missions.

The Bluefin team recently successfully demonstrated the BPAUV in March, 2001, over the mine-fields installed for Kernel Blitz '01. The BPAUV executed 135 hours of bottom mapping, change detection, and mine-hunting missions during the course of the exercise. Numerous mine targets were detected and classified. Once completed, the pressure-tolerant batteries will be installed and demonstrated on-board the BPAUV.

A second program, the *US/UK Collaboration on UUVs for MCM Applications*, for which Bluefin will build two BPAUV-style vehicles, will also use the Pressure-Tolerant Batteries to provide a robust, high cycle-lifetime energy module for these vehicles.